Quench calculation for the CBM Dipole magnet

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The CBM dipole magnet will store about 5.15 MJ at its nominal current of 686 A. When designing the quench protection scheme for the CBM magnet it is important to estimate the overall characteristics of the quench process in the coil.

Three types of the quench calculation were performed for the CBM dipole magnet: ”first approximation”, instantaneous quench and 3D calculation using GSI[1] and CIEMAT[2] quench programs.

The ”first approximation” is a simplified calculation which can be used to obtain the good order of magnitude of average coil temperature (T_{av}) and maximum quench voltage (V_{qm}) for self-protecting magnets. T_{av} can be derived out of following equation:

$$\frac{E}{Vc} = \int_{4.5K}^{T_{av}} C_v(T)dT \tag{1}$$

where E is the magnet energy, Vc is the coil volume and C_v is the volumetric specific heat. In our case Tav is 90 K.

Having T_{av} one can estimate V_{qm} using an empiric formulation[**?**]:

$$V_{qm} = 0.403 * R_{pole}(T_{av}) * I_n \tag{2}$$

where I_n is the nominal current and $R_{pole}(T_{av}) = \rho_{Cu}(T_{av}) * 1749 * 5/A_{Cu}$. In this case $R_{pole}(T_{av}) = 4.7\Omega$ and $V_{qm} = 1307V$.

The instantaneous quench means that the whole coil is heated up instantaneously above the critical temperature. It is assumed that one coil has one uniform temperature (T_{av}) and field (B_{av}) distributions. At the start of the quench T_{av} is equal to 10 K and $B_{av} = B_{max}(I_n)/2$, where I_n is the nominal current.

For a short-circuited magnet electrical equation[3] gives the following current decrease:

$$dI = -\frac{R_q(T_{av}) * I}{L_d(I)} * dt \tag{3}$$

where L_d, R_q is the differential inductance and resistance of the coil, respectively. dt is the time which corresponds to the current increase[3] dI. From the heat equation written for one pole one can get the following temperature increase:

$$dT_{av} = \frac{R_q(T_{av}) * I^2}{Vc * Cp_{av}(T_{av})} * dt \tag{4}$$

where Vc is the coil volume, Cp_{av} is the average specific heat. The instantaneous quench calculation takes into account the inductance function $L_d(I)$ and the $B_{max}(I)$. It gives the average temperature of about of 90 K. The resistance of quenched pole is equal to 4.7 Ohm and the maximum quench voltage is equal to 1230 V.

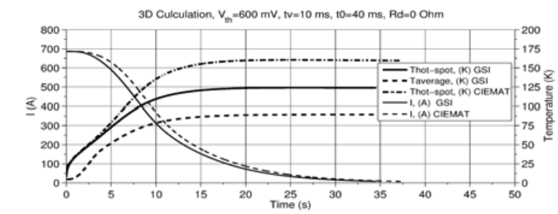

Figure 1: 3D quench calculation of the CBM dipole – the magnet current, hot-spot temperature and the average coil temperature.

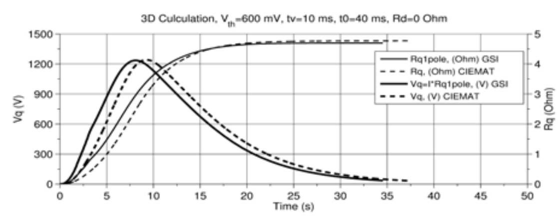

Figure 2: 3D quench calculation of the CBM dipole – the quench voltage and the quench resistance.

The 3D quench analysis has been performed using GSI[1] and CIEMAT[2] programs. The results of calculations when no dump resistor was used are presented in Fig.1 and Fig.2. The difference between the results calculated with the GSI and CIEMAT models is related to the different field map distribution in the coil, and also to different material data bases used in those programs. The maximum hot-spot temperature and quench voltage equals to 160 K and 1240 V, respectively.

The presented results show that the CBM dipole magnet is a self-protecting.

References

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